ENVIRONMENTAL SENSING USING TACTICAL MCM SYSTEMS

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Award #: N00014-96-WX-30452

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LONG TERM GOAL

The long term goal of this effort is to demonstrate that MCM reconnaissance systems presently under development and planned for use in UUV platforms can be used to make critical environmental measurements while operating in the MCM reconnaissance mode. In addition, it is planned to investigate the possible feedback of the environmental information measured on-scene into the UUV for use in automatically adapting the programmed mode setting of the platform to account for changing environmental conditions.

OBJECTIVES

The objective of this project is to determine the potential of and develop capabilities for the Toroidal Volume Search Sonar (TVSS) to provide in situ environmental measurements of use by the MCM force for predicting MCM system performance, determining optimum mode settings, and in conjunction with other remote sensing systems, providing an overall environmental scene description of the MCM objective area. The environmental parameters targeted are sediment classification and properties (grain size, porosity, strength, etc.) using the vertical incident TVSS beam, bathymetry using multi-beam concepts, sediment roughness using the TVSS as a side scan sonar, and areal sediment property provincing and segmentation using the sediment classification, multi-beam bathymetry, and side scan data. As stated above, the longer term objective is to use the on-scene measurements as feedback into the platform's processor in order to change programmed system mode settings on-the-fly in order to maintain optimization of the system's performance. The TVSS is presently under development at the Naval Surface Warfare Center's Coastal Systems Station (CSS), Panama City, FL and is planned as a major component of the future Remote Minehunting System (RMS).

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **30 SEP 1997**	2. REPORT TYPE	3. DATES COVERED **00-00-1997 to 00-00-1997**

4. TITLE AND SUBTITLE **Environmental Sensing Using Tactical MCM Systems**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Code 7430,Stennis Space Center,MS,39529**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**8**	

APPROACH

The basic approach toward meeting the project's objectives is to coordinate an algorithm development program with planned sea test milestones of the TVSS program conducted by CSS. The initial effort included obtaining existing TVSS data from CSS and "conditioning" the data for use by existing algorithms developed for similar data collected by other sensors and platforms. The algorithms to be used include the BOGGART bottom backscatter and forward loss prediction model developed at ARL:UT and which uses Biot parameters to estimate sediment properties, the bottom roughness scattering model developed at APL:UW for estimating bottom roughness and sediment properties, multi-beam bathymetry techniques developed by Scripps which use a split-aperture beamforming concept, and provincing and mapping schemes developed at WHOI. Once the capabilities and limitations of the TVSS are defined, suggested changes to the TVSS (e.g., transmit power levels, additional platform roll measurements, vertical incident beam width, etc.) will be made to CSS for possible improvements to the environmental data collection capabilities of the system. In addition, the processing algorithms will be modified/improved to work better with the TVSS system and its resultant data. Next, the TVSS, with or without the suggested improvements, will be fielded in a carefully selected test area containing a wide spectrum of bottom types and conditions. Significant ground truth data will be collected in order to quantify the capabilities of the TVSS to make environmental measurements. This sea trial will leverage a planned sea test of the TVSS as part of the RMS development effort. Following this quantification, an effort will commence to develop feedback algorithms using the collected environmental data for use in continually optimizing the reconnaissance capability of the TVSS/RMS.

WORK COMPLETED

TVSS data has been received from CSS. This data has been evaluated and "conditioned" for use by the various investigators involved in the effort. Work to date using the BOGGART and bottom roughness scattering models has clearly shown that the TVSS can in fact determine sediment types and provide certain sediment properties such as grain size. Because no ground truth data was available for the two TVSS data locations, a literature search was conducted to determine likely sediment properties of the test sites.

RESULTS

The literature search showed that the BOGGART and bottom roughness scattering models were "correct" in their determinations. With essentially no knowledge of the sediment types of the two TVSS test areas (other than an intelligent "guess" that both sites were composed of typical Panama City area coarse sands), these models predicted that the sediment type for the shallow site was coarse, large diameter sands and that the deeper site was a much finer-grained silty clay.

The BOGGART model contains empirical relationships that are used to estimate Biot parameters, such as porosity from grain size, and to compute reflection coefficient, R. In figure 1 (provided by N. Chotiros, ARL:UT), resultant plots of R as a function of porosity and grain size are presented. In this figure, grain size is given in phi units, defined as the negative of log base 2 of the grain diameter in millimeters (therefore, the higher the phi value, the smaller the grain size). From these plots, the R values from the deep and shallow sites indicate very different bottom types. Estimated porosity of the shallow site is 50% or less, indicating a hard bottom (i.e., coarse sand), and the porosity of the deep site is estimated to be 90%, indicating a very soft bottom (likely a silty clay). The grain size analysis shows phi units of 3 or less for the shallow site (representing a wide variety of sands) and phi units of almost 10 for the deep site (indicative of a very soft clay).

In the APL:UW analysis, the TVSS vertical beam data was used for sediment property inversions, and the beam 30 degrees from the vertical was used to estimate scattering strength (at a grazing angle of 55 degrees). These measurements were compared with the predictions made from the APL:UW backscatter model. Using ping averaging, estimates were made for each 40 meters of the TVSS track for the deep site. Using a 4-parameter model, values were computed for bottom loss at vertical incidence, absorption, sediment volume scattering, and angular spread. As a byproduct of this process, sediment grain size can be computed. Figure 2 (provided by D. Jackson, APL:UW) shows the grain size analysis (top) for the deeper water site. Phi units agree well with those estimated by Chotiros presented in Figure 1, indicating silty clay sediments. Also presented in Figure 2 (bottom) is a plot of the corresponding scattering strength values generated from the APL:UW scattering model which shows that the scattering strength values do not vary greatly, remaining within a 10 dB band. However, the measured scattering strength is virtually constant along the 1200 meter track. It appears that the variability may be due to the narrow TVSS beams (wide beams are preferred) and perhaps to significant roll of the TVSS vehicle. Adaptive algorithms (and perhaps additional roll measurements by the TVSS system) could be developed to compensate for these effects.

To provide some credibility to these TVSS results provided by Chotiros and Jackson, Dr. Fred Bowles (NRL) conducted an in-depth literature search of the Panama City area containing the two TVSS sites. Although no data was found in the exact TVSS locations, enough evidence was available for the surrounding areas to clearly show that the TVSS sediment property estimates were correct. Figure 3 (Ludwick, 1964) shows variations in water depth (top) and percent sand (bottom) along a transect which passes very close to the deep site and within about 15 miles of the shallow site. Dredge samples taken at approximately quarter mile intervals were used to develop this figure. The bottom profile clearly shows that the deep site is probably composed of about 20% sand and that the shallow site is almost totally composed of sand. Ludwick (1964) also prepared ternary diagrams (Figure 4) showing the textural and compositional make-up of the so-called Western Florida Lime-Mud Facies (in which the deep TVSS site is located) and for the Cape San Blas Sand Facies (the shallow TVSS site). Although the Lime-Mud Facies is bimodal (Figure 4B), it is evident with either mode that the sediments at the deep site consist of substantial amounts of silt and clay (up to 95%). In contrast, the shallow site (Figure 4B) is strongly composed of terrigenous and some carbonate sands. Similarly, plots of grain size (in mm) versus cumulative frequency (Figure 5) show that medium- to coarse-grained sands predominantly make up the Eastern San Blas Sands representing the shallow site, whereas the Western Florida Lime-Mud Facies representing the deep site consists of finer-grained material. The projected differences in grain size between the two sites are consistent with the determinations made by Chotiros and Jackson.

The TVSS multi-beam data was also used to develop a side scan map along its track at the deep site. Unfortunately, this test area is extremely flat with no discernible roughness or morphological features. With close inspection, the resultant side scan image, however, does appear to show that the TVSS can be used in this mode.

Data conditioning and split aperture beamforming have been completed by C de Mustier at SIO, and the multi-beam bathymetric mapping effort is just getting underway. Once the bathymetric mapping effort has produced bathymetric maps, K. Stewart at WHOI will commence the provincing and segmentation effort using the map, sediment properties, and side scan data.

IMPACT/APPLICATIONS

Mine Countermeasure (MCM), Amphibious, and Naval Special Warfare operations are normally conducted in shallow water and coastal areas where bottom characteristics, sea surface conditions, oceanographic structure, and atmospheric influences strongly determine the effectiveness of sensor and system performance. This dynamic littoral environment is characterized by extremely spatial and temporal variability. In addition, most of the potential operational areas are in denied areas in which limited environmental information exists. At present, the US MCM force does not have a capability to collect required environmental information in a planned MCM objective area. This deficiency severely limits optimum tactical planning for setting MCM system mode settings and determining most efficient use of available MCM assets. A potential solution to this deficiency is to use MCM reconnaissance systems presently in development to provide environmental measurements in an objective area while operating in the MCM reconnaissance mode in a denied area. In addition to establishing initial mode settings for MCM and other combat systems using this collected data, the potential exists to develop real time, environmentally-adaptive systems by using the sensed environmental data on-the-fly to continually optimize the performance of the system/sensor. A third application of environmental data collected in this manner is to “fuse” the in-water measurements with the much wider area data collected with airborne and satellite remote sensing systems. This combination will allow “calibration” of the remote sensor data and will allow the development of an overall environmental description of the battlespace.

TRANSITIONS

This effort has two transition sponsors. Relative to performance prediction and automated environmentally adaptive capabilities of the TVSS, the sponsor would be PMS-407 via Pre-Planned Product Improvement (P^3I) initiatives within its Remote Minehunting System (RMS) program in which the TVSS will be a major component. Relative to overall environmental description of the battlespace, N85 (Expeditionary Warfare) would be the sponsor within its MCM TDA development effort.

RELATED PROJECTS

The milestones of this project are tied directly to on-going programs at both the Naval Surface Warfare Center's Coastal Systems Station (CSS) and the Naval Research Laboratory (NRL). It is linked to the TVSS (and hence the Remote Minehunting System (RMS)) presently on-going at CSS. In addition, this effort is related to the Environmental Acoustics Support for MCM program presently underway at NRL. Field data collected by these programs will be made available for use in this effort. NRL is also presently conducting a program entitled "Remote Minehunting System-Oceanographic Variant" in which it is developing oceanographic sensing capabilities for its ORCA semi-submersible, untethered vehicle. An important aspect of this program is the development of real time feedback to the vehicle to optimize its oceanographic survey mode settings such as track line spacing. The results from this effort will be the starting point in the automatically adaptive objectives for the TVSS. A generic system performance prediction models developed at CSS (the Shallow Water Acoustic Toolkit (SWAT)) has been provided to NRL and will be used and supported. The bottom roughness scattering model, the split-aperture beamforming bathymetric mapping techniques, and the provincing and segmentation techniques were all funded within ONR programs.

REFERENCES

Two technical reports have been completed this past year.

Bowles, Frederick, 1997. "Sediment Characteristics of Toroidal Volume Search Sonar (TVSS) Test Sites Off Panama City, Florida." Naval Research Laboratory, NRL/MR/7432—97-8058, dated 17 July 1977.

Chotiros, Nicholas, 1997. "Feasibility of Bottom Classification With the Toroidal Volume Search Sonar (TVSS) - Progress/Technical Report." Applied Research Laboratory:University of Texas at Austin, Technical Report ARL TL-97-11.

Data and figures from the paper referenced below were used in the preparation of this report.

Ludwick, J.C., 1964). "Sediments in Northeaster Gulf of Mexico." In R.L. Miller (Ed.), Papers in Marine Geology, Shepard Commemorative Volume. MacMillan, N.Y., 204-238.

ESTIMATION OF (a) POROSITY AND (b) GRAIN SIZE FROM REFLECTION LOSS PREDICTIONS BY BOGGART v.3

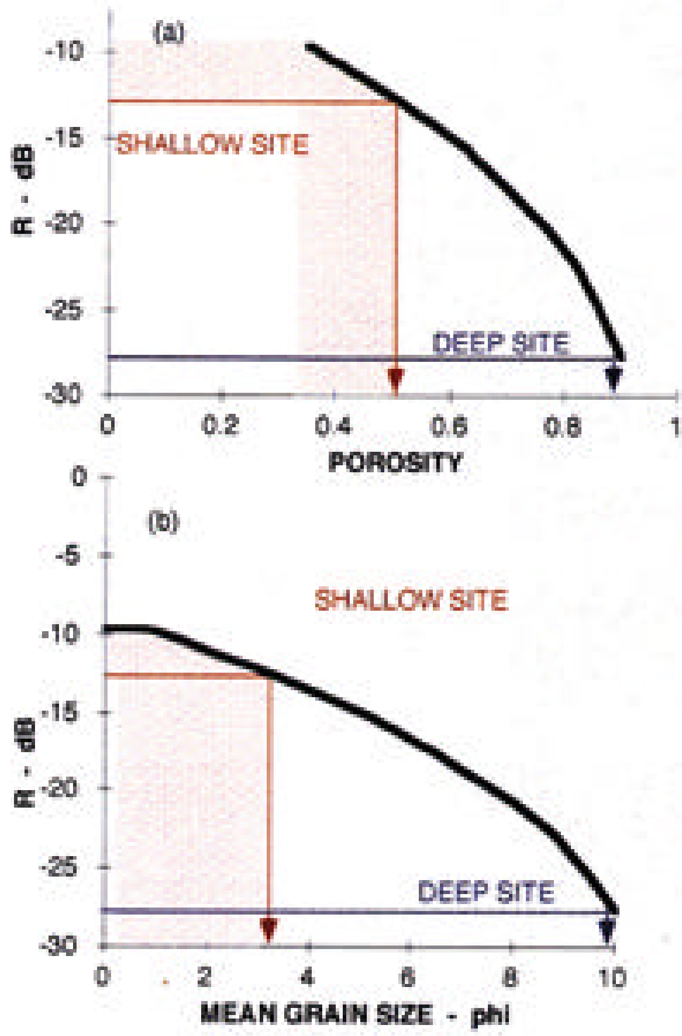
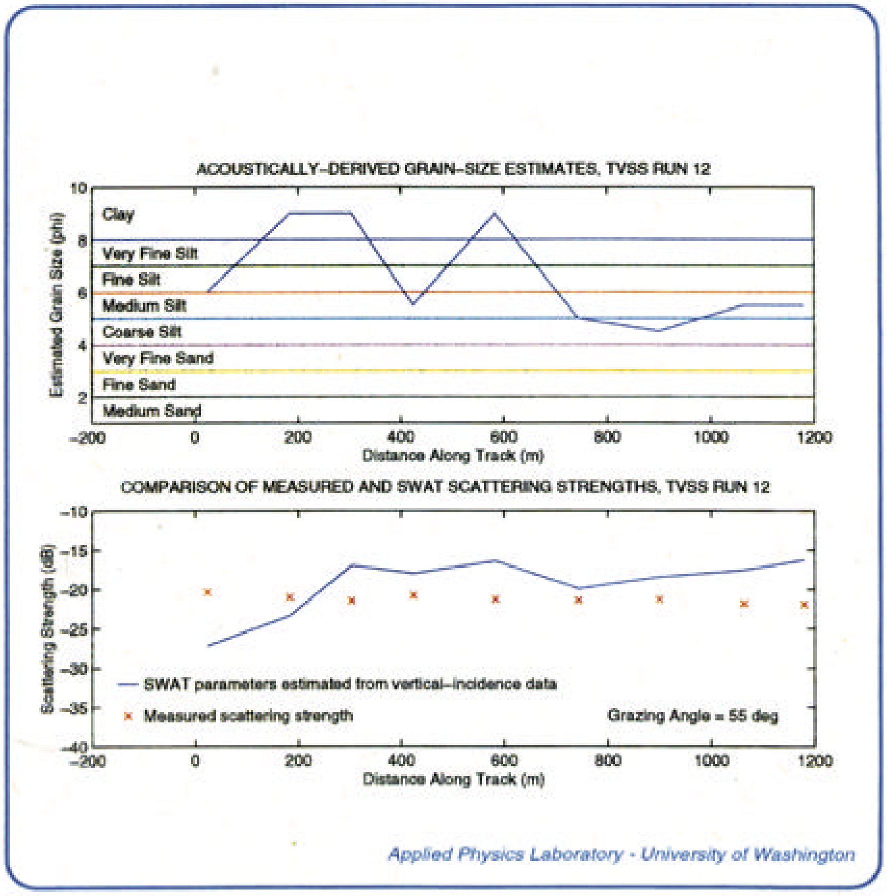


Figure 1



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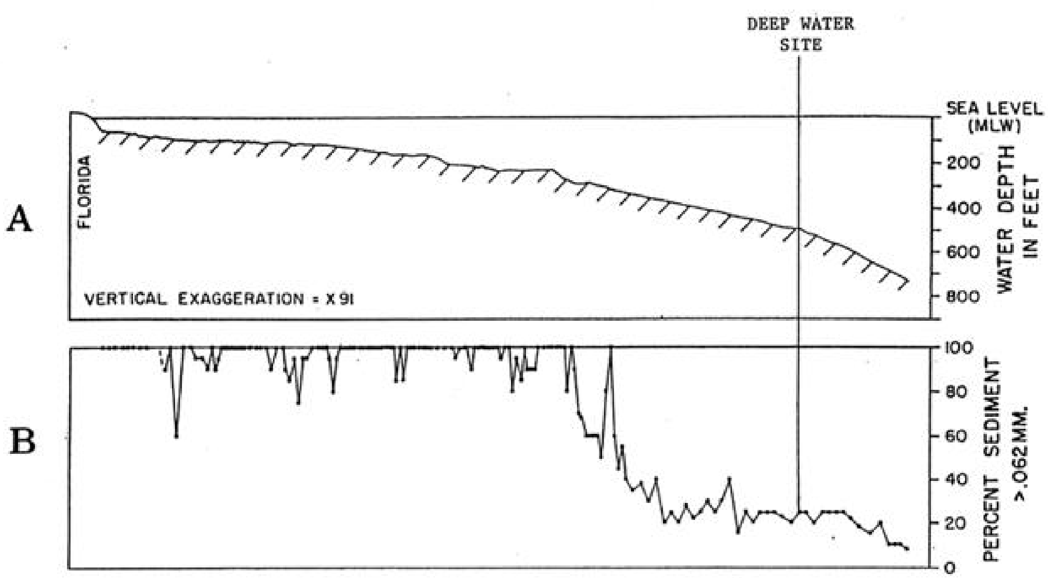

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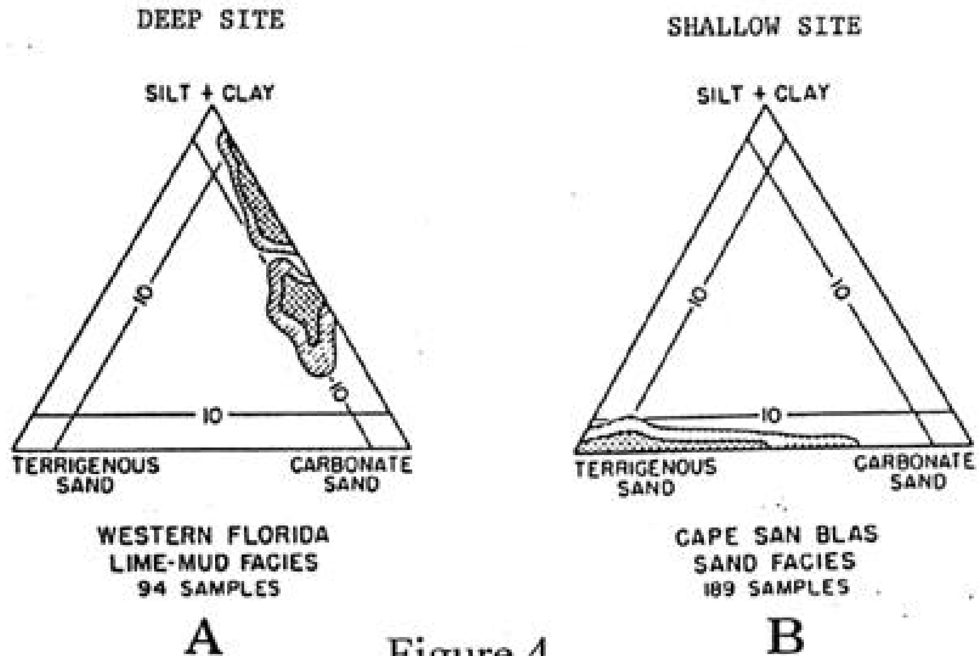

Figure 4

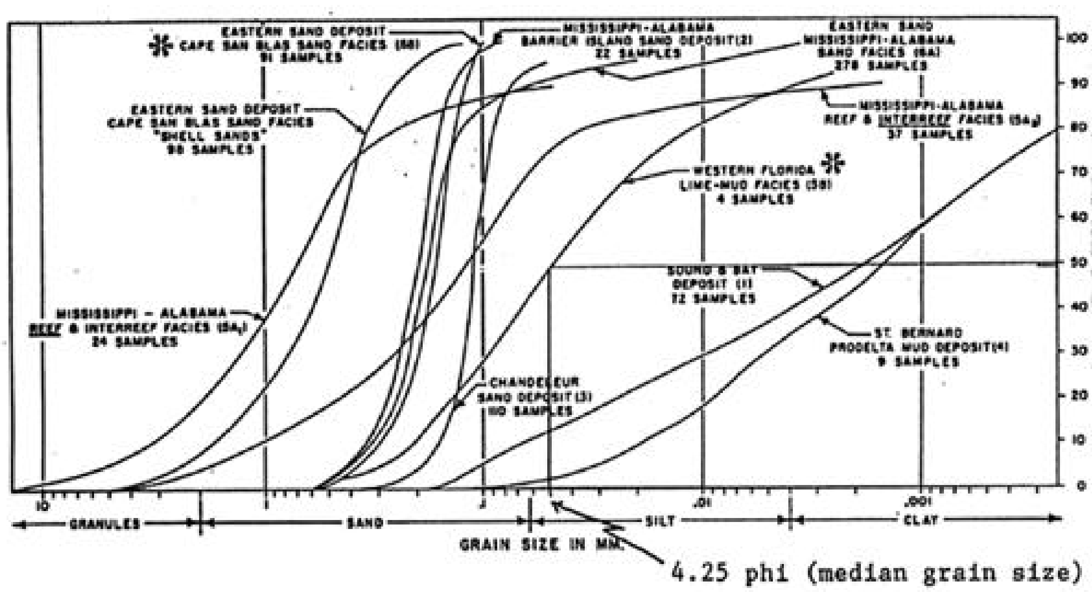

Figure 5